

# **Displacement Damage in Silicon due to Secondary Neutrons, Pions, Deuterons, and Alphas from Proton Interactions with Materials**

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## **Abstract**

The enhancement of displacement damage energy deposition due to secondary neutrons, pions, deuterons, and alphas resulting from high energy proton interactions with aluminum and tungsten shielding are examined in this paper.

## **Summary**

As particle energies become higher, their DeBroglie wavelength becomes short compared to the size of the target nucleus. Under these conditions, a new reaction type called spallation takes place in addition to the usual Coulomb and nuclear elastic/inelastic scattering. The products of the spallation reaction can be important for the accurate assessment of the radiation effects. The products include, but are not limited to, secondary protons, neutrons, pions, deuterons, and alphas. In this study, we investigated the effect of secondary particles (neutrons, pions, deuterons, and alphas) on the displacement damage energy deposition in silicon resulted from high energy proton irradiations through aluminum and tungsten shields.

The displacement damage energy deposition can be computed if the particle spectrum and the Non-Ionizing Energy Loss (NIEL) of that particle as a function of energy are known. The NIEL plays the same role to the displacement damage energy deposition as the stopping power to the total ionizing dose (TID). There have been various studies that have shown the degradation of semiconductor devices or optical sensors in a radiation environment can be correlated to the displacement damage energy, and subsequently to the NIEL, deposited in the semiconductor devices or optical sensors.

The accurate calculation of displacement damage energy deposition in a material due to the high energy protons that include the contributions from secondary particles requires knowledge of the NIEL and the energy spectra of each relevant secondary particle species. There have been the studies where the effects of the secondary neutrons and/or secondary protons were extensively addressed, however, the assessment for other species of secondary particles have not been easy, since the NIELs were not available, or there weren't any radiation transport codes that could compute the energy spectra of those secondary particles. Therefore, the effects of other secondary particles were often considered to be insignificant, or some arbitrary safety margins (30-50% on top of the neutron contribution) were applied to accommodate the uncertainty associated with neglecting their contribution to displacement damage energy deposition. This paper quantitatively addresses the displacement damage energy deposition from secondary pions, deuterons, and alphas for the first time, as well as from secondary neutrons. The displacement damage energy deposition calculations used published NIELs and used the recently developed Monte Carlo charged particle transport code, MCNPX 2.1.5.

Only simple spherical shield geometry was considered in this summary. The problem geometry consists of a 0.5-cm radius silicon sphere surrounded by various thicknesses of aluminum and by various thicknesses of tungsten. Aluminum and tungsten were chosen as the representative light (low/medium atomic number) and heavy (high atomic number) shielding materials in this study, respectively. The

shielding thicknesses ranged from 0.69 g/cm<sup>2</sup> to 20.6 g/cm<sup>2</sup> for either material. The 500 and 1000 MeV protons were assumed to be isotropically incident on the outer surface of the shielding material, and the volumetric displacement damage energy deposition over the silicon region was computed. The results obtained in this way were then compared to those obtained using NOVICE, which employs the continuous slowing down approximation (CSDA) without any secondary particle consideration.

Figures 1 to 4 summarize the results, respectively, for 500 MeV and 1000 MeV proton irradiation into aluminum tungsten spherical shields. A few brief observations are as follows: (1) The enhancement due to secondary protons is within +20% for either material, (2) Most of the secondary effects are due to neutrons, (3) The combined effects of secondary pions, deuterons, and alphas are small compared to the enhancement due to secondary neutrons, (4) The enhancement factor due to neutrons is much larger for tungsten than for aluminum for the same shield thickness in g/cm<sup>2</sup>, (5) The secondary effects are more important for the higher energy protons than for the lower energy protons.

Therefore, the results showed that most of the secondary contributions are from the secondary neutrons, quantitatively justifying the reason why some of the previous studies concentrated solely on the secondary neutrons. The secondary pions, deuterons, and alphas produced from the 500 and 1000 MeV proton interaction with aluminum or tungsten account for maximum 10% enhancement in very thick shielding applications.

The present study described only the mono-energetic proton cases in a very simple geometry in a very brief manner. A full and detailed discussion of the results will be addressed in the final paper. Furthermore, the present work will be expanded to address more complicated geometries (such as secondary effects on Star Tracker CCD used in many JPL flight projects), and use real space proton environments.

#### **Partial List of References**

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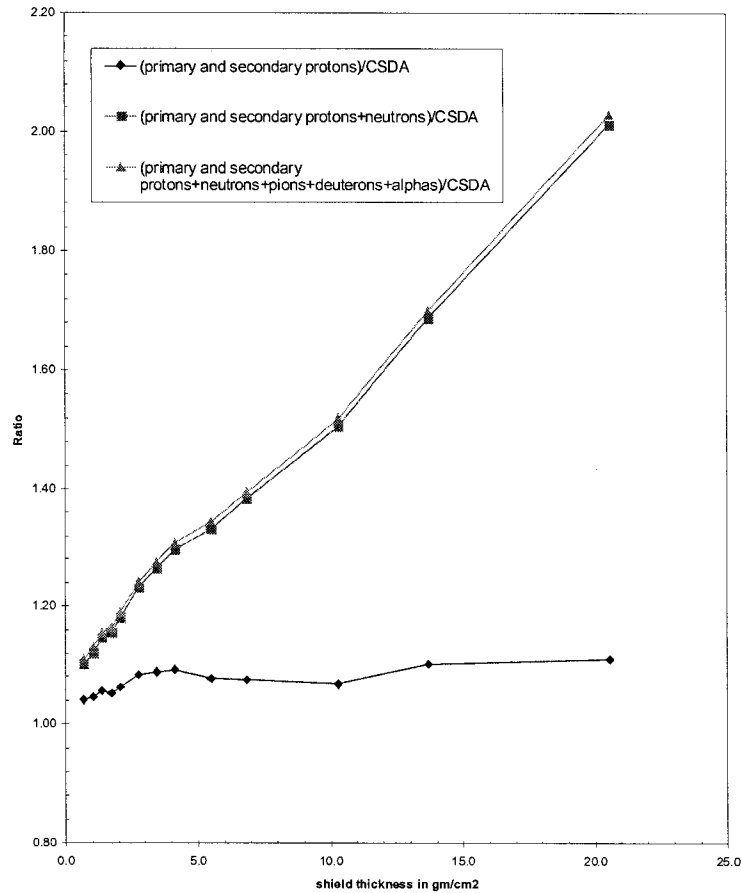


Figure 1. Effects of secondary particles on the displacement damage energy deposition as a function of aluminum shield thickness for 500 MeV protons. The results are presented in terms of the ratios to the CSDA results. The problem geometry is described in the text

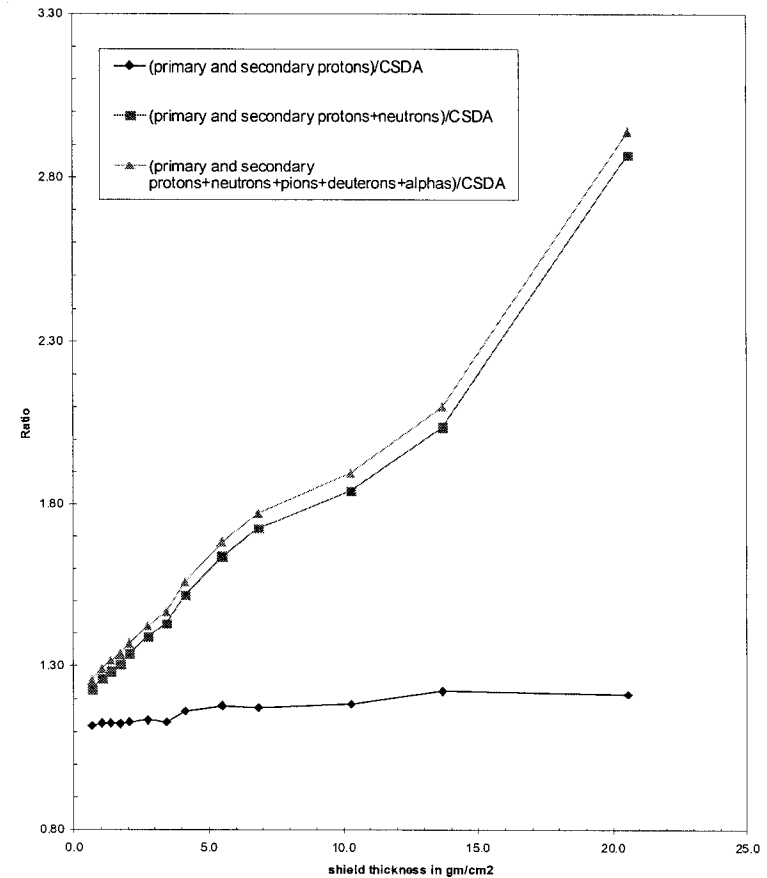


Figure 2. Effects of secondary particles on the displacement damage energy deposition as a function of aluminum shield thickness for 1000 MeV protons. The results are presented in terms of the ratios to the CSDA results. The problem geometry is described in the text.

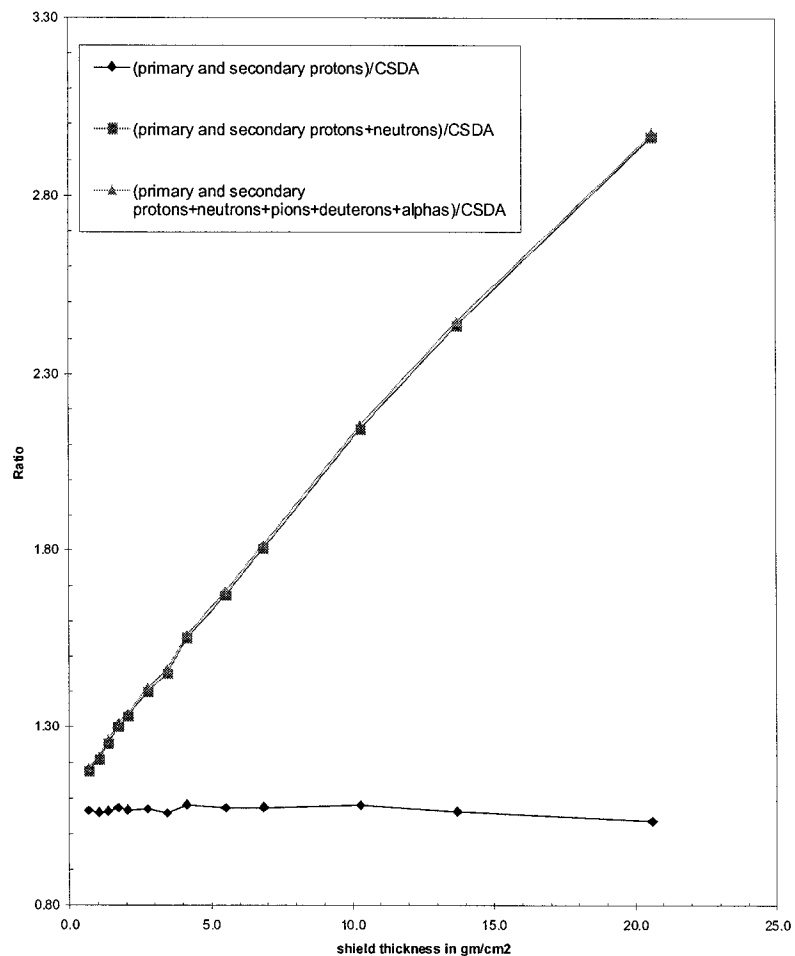


Figure 3. Effects of secondary particles on the displacement damage energy deposition as a function of tungsten shield thickness for 500 MeV protons. The results are presented in terms of the ratios to the CSDA results. The problem geometry is described in the text.

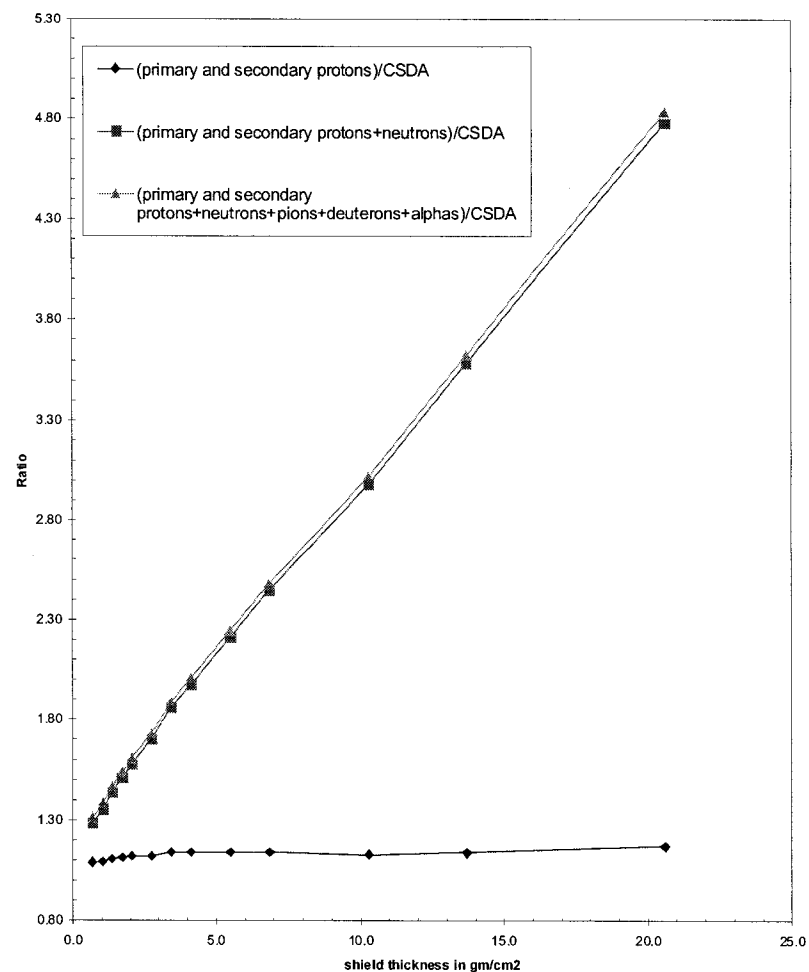


Figure 4. Effects of secondary particles on the displacement damage energy deposition as a function of tungsten shield thickness for 1000 MeV protons. The results are presented in terms of the ratios to the CSDA results. The problem geometry is described in the text.